RSRE
MEMORANDUM No. 4272

ROYAL SIGNALS & RADAR ESTABLISHMENT

THE AUTOMATIC DETECTION OF ANTI-COLLISION LIGHTS

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AUTHOR: Brian A Wyndham

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SUMMARY.

Recent instances of mid-air collisions and near-misses between aircraft at low level have emphasised the need for some form of aid to provide earlier visual warning of potentially dangerous situations. This memorandum describes the nature of the problem to be overcome and proposes the use of a cockpit image sensor and advanced image processing techniques.

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THE AUTOMATIC DETECTION OF ANTI-COLLISION LIGHTS.

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1. INTRODUCTION.

Recent instances of mid-air collisions involving high performance aircraft at low level have emphasised a need for some aid to provide advance warning of potential threat situations not only between similar aircraft but especially those involving light aircraft and helicopters.

The pilot of a high performance military aircraft at low level has a high work-load and must keep a look-out for other aircraft which may be in his flight path. To assist with this, anti-collision lights are fitted to aircraft to draw attention to their presence. However, it would appear that in most cases the lights are not seen as easily as would be desirable even though they are being sought and work by the Royal Aerospace Establishment and the Institute of Aviation Medicine has shown that very bright lights are needed to attract attention in the peripheral vision zone.

Frazer[1] points out that an aircraft flying at 420 knots will collide with another aircraft flying at 80 knots on a convergent track bearing about 11°. A 60° banked turn evasion requires a detection range of 3 500 metres and a 3 g pull-up requires a detection range of 1 850 metres. An unspecified "violent avoiding action" requires a detection range of at least 1 000 metres.

Smith[2] concludes that:

"For a strobe light that is well above the threshold of detection (well inside the liminal range), the probability that the pilot of a high performance aircraft will see that light in sufficient time to take collision avoidance action is, on the basis of the Institute of Aviation Medicine experiments, at best no more than 1 in 4 (25%) and on the basis of the flight trials is even less. Even these modest levels of peformance will only be achieved if the point of fixation and the location of the light are virtually coincident (within 1°).

"There is a high probability that strobe lights of the type tested (1 250 ECP) in the flight trials will not be detected until the aircraft is within the 'violent' avoiding action range."

It should be noted that in the interval between two consecutive flashes, the range will be reduced by 216 metres and consequently in the time it takes to establish that the lights are of significance, the aircraft will be much closer than when the light was first noticed.

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[1] Fraser, C.J., Agricultural Aircraft Conspicuity: Strobe Lights. *DTRD Report No 8102, 5C/9/163/01.*

[2] Smith, A.J., The Use of Flashing Lights to Enhance the Conspicuity of Crop Spraying Aircraft. *RAE Tech Memo FS(B) 564.*

The RAE trials used lights which were deemed suitable for light aircraft by virtue of their size and power consumption. The strobe lights flashed at 1 Hz with outputs of 825 and 1 250 Effective Candle Power (ECP). The rotating beacons flashed at 2-2.5 Hz with outputs of 4 000 and 1 500 ECP with an effective flash duration of 7 msec.

Smith and Chapelow[3] concluded that flash rates in the range 1-2 Hz are acceptable and an increase beyond that range would not likely to be beneficial if it necessitates a reduction in brightness. Also, although a 4000 Candela strobe light is likely to improve the visibilty of low flying aircraft, increasing conspicuity to guarantee a high detection probabilty beyond 3.5 km is unlikely to be a practical prospect using flashing lights.

Much low level military flying is done in mountainous areas whilst following contours around high ground and it is evident that long range visibilty is impossible. If flying curved tracks in opposite directions around a hill, the use of terrain following radar would almost guarantee their meeting without either becoming aware of the other in time to take avoiding action. Two aircraft approaching each other at a closing speed of about 800 knots would require a detection range of about 7 Kms. It is also probable that in that scenario, the use of electronic methods such as the Traffic Alert and Collision Avoidance System (TCAS) would also not be effective because of limitations due to screening by the intervening hill.

When two aircraft are flying straight and level and on collision course their relative bearings are constant, irrespective of their relative tracks. Consequently one is denied one of the features which might be used to attract attention. that of apparent relative motion. Hirst and Hirst[4] state that without lights, the other aircraft only becomes an apparent hazard when it has approached near enough to appear about 8 mins of arc in width. This assumes that the pilot's eye has become focussed to about arm's length and the other aircraft appears blurred.

The research task is, therefore, to discover how the features of the exterior scene may be exploited to emphasise the object of interest whilst minimising the number of false alarms.

2. THE OBJECTIVES.

The need is to be able to detect visually the presence of another aircraft in order to comply with the concept of "SEE AND AVOID" and it is proposed that an instrument could be designed to detect the presence of another aircraft's lights and draw the pilot's attention to the direction of the hazard.

The device required is not intended as an alternative to TCAS or other system based on SSR which require all aircraft to carry a working transponder. The need here is for a relatively simple concept which is more in the nature of an electronic eyeball.

The success of such a device in use will depend on how well it can cope with a wide variety of conditions whilst meeting the needs of the user. A number of identifiable

[3] Smith, A. J. & Chappelow, J.W., Agricultural Aircraft Anti-collision Lighting for Daytime Use. *RAE Report FS(B) WP(87)008.*

[4] Hirst, L. & Hirst, R., *Pilot Error, p142.*

problem areas will be encountered and certain constraints will have to be imposed in order not to make their solution unnecessarily difficult.

The visibility of aircraft lights is dependent on several factors among which are, with varying degrees of importance:

- Lamp brightness;
- Background brightness;
- Contrast;
- Size of light source;
- Flash rate;
- Flash duration;
- Colour;
- Atmospheric conditions;
- Position in the field-of-view;
- Relative speed across field of view;
- Vibration of observer's aircraft;
- Clarity and cleanliness of windows;
- Distance from observer;
- Distractions due to other lights, reflections etc;
- Glare from sun;
- State of observer's eyesight;
- The mental processes of observation.

One must distinguish between visibility and awareness; once a lamp has been seen it may be easier to find again but the problem is that of first becoming aware of its presence.

Often, the observer sees the dark shape of the other aircraft before noticing the lights. This would be the case when an aircraft is seen against a background of sky but it is self evident that a camouflaged military aircraft may be difficult to see against a background of vegetation.

The need therefore is to detect an anti-collision light against a background of sky, cloud, haze or land with various covers which may be vegetative, mineral or water. The light could be from xenon strobes or filament lamps flashing at approximately 1 Hz.

3. SYSTEM REQUIREMENTS.

The basic requirement is for the device to detect another aircraft's lights at ranges of at least 3 Kms. It must have a low false alarm rate and not be confused by the sun, stars or other lights which are of no significance. The device should indicate to the pilot the approximate direction of the hazard and be capable of being cancelled once the warning has been heeded.

3.1 FIELD OF VIEW.

An all-round field of view would be ideal but a more practical limit would be that imposed by the cockpit canopy. The reason for this line of thinking is that if a detection is advised to the pilot he will wish to cancel the warning once he has made visual contact. Continuation of a warning long after it has been heeded would be unnecessary and annoying. To give a warning of another aircraft he cannot see or be in hazard with, would not only occupy processing time which could be used for searching a more profitable area but would continue to give an alarm until cancelled. Continual warning of companion aircraft flying together is also undesirable.

There is also the certainty that the aircraft's own lights would be observed if the detector were positioned for all-round vision. In this case, one's own xenon strobe lights could conceivably be gated out by blanking from the trigger pulse but this is less practicable for filament lamps.

Initially therefore the field of view should be limited to a reasonable forward looking angle which allows the use of readily available lenses and a 30° field of view is suggested.

3.2 FLASH DETECTION.

An optical system will respond to any inputs within the photo-sensitive range of the detector. Some of these may be from natural highlights such as the sun and the sky and their reflections in water or glass. These will generally be of a steady nature but from a moving aircraft the effects of intermittent screening and glinting from reflecting surfaces will generate a fluctuating component which will not be regular.

Artificial lights may be steady or flashing at various rates up to that of the frequency of the supply voltage if they are the electric discharge type. Those which are specifically desired to be detected will have a flash rate between 1 and 3 per second. Being regular these should be distinguishable from glinting and screening effects. It must be borne in mind that other flashing light sources may be from police and emergency vehicles on the ground certain types of obstruction lights on masts and lighthouses.

The extension of the concept to include fixed obstruction light detection would seem to be desirable but many obstructions are marked by steady lights which have little in the way of identifying characteristics which would be amenable to machine recognition.

The possibility that a more reliable system may be attained by the use of tightly specified flash rates and coded flashes should not be overlooked but it must also be accepted that some aircraft carry several lights including navigation lights which may or may not flash synchronously.

The rotating reflector type of flasher often has a second flash due to internal reflections from the lamp cover. Unlike the Xenon strobe lamp, the effective flash duration and brightness are also dependent on the angle of view in the vertical plane. When observed from a point above or below the principal optical plane, the flash appears longer and dimmer. This fact points to the desirability of using xenon strobes

exclusively.

The problem of companion aircraft flying in line may not be trivial for those behind the leader. The lights of preceding aircraft will generate an alarm and only the leader would be in a position to detect a hazard with any certainty.

One solution might be to only activate the leader's sensor in this situation but this is not seen as totally satisfactory and requires a positive action to re-activate the sensor when the aircraft separate.

Another technique would be to synchronise the flashers of all group members by some means so as to allow the sensors to be gated to give a different warning from that of an intruder. The pilot would then still be aware of his companions should they also become a hazard but would only be practicable for xenon flash lamps.

If the role of the device is seen only as identifying light aircraft in the path of fast military aircraft, it may be that it should be a requirement for the light aircraft to carry a strobe light which is triggered either by the military aircraft's IFF or TACAN interrogator. The flashes would then be synchronisable to the flash detector. This concept is not new and was tried as an early form of IFF. It would be necessary to provide for a countdown from the basic repetition period to a rate close to that of the visual system. Obvious problems would be those generated by several aircraft flying together, each attempting to trigger the one lamp and the objections from cost and weight conscious light aircraft owners.

The warning could also be based on the detection of the faster aircraft's strobe lights rather than the other way round but there is a difference in that a detector in the slower aircraft would need to have an all round view whereas a detector in a fast aircraft requires an emphasis in the direction of flight.

4 ALTERNATIVE SYSTEMS.

It has been assumed so far that the avoiding action will be taken by the faster aircraft but it would seem that evasive action by the slower aircraft may be more effective because

- The pilot has a lower work-load;
- The aircraft is more agile;
- The evasive action is more predictable.

The latter factor is stated on the assumption that low flying military aircraft are, or should be, no lower than 250 feet above the ground whereas crop sprayers work closer to the ground whilst actively engaged in spraying. At the end of each spraying run, the aircraft climbs and turns for the next strip and it may be conjectured that a collision hazard exists at this time because the pilot will have got into a routine and not have had time to observe the approach of another aircraft.

If the crop sprayer were to remain at low level there should be no collision hazard or, if the approach of another aircraft could be advised to the crop sprayer pilot, his

obvious action would be to descend below 250 feet.

Many near miss occurences involve helicopters, often engaged on pipeline inspections which require the pilot to be preoccupied with the ground below. Such a pilot would consider his workload to be high. The helicopter escape manoeuvre is most likely to be a descent but some reported near-miss occurences have necessitated a climb.

5. THE SENSOR.

No mention has yet been made of the nature of the sensor but the ready availability of solid state focal plane multi-pixel arrays would allow an early start to be made on experimental work and the techniques proposed here are related to the image processing methods used for remote sensing.

The most suitable device is based on the Charge Coupled Device Photodiode Detector (CCDPD) array which is available in linear, area and circular configurations. These have advantages over other types of photo detector with regard to sensitivity, dark current and more importantly in this application, low lag and blooming.

The CCDPD array has a sensitivity which peaks in the red part of the spectrum at about 0.75 nm unlike the eye which peaks at 0.55 nm. Furthermore, the sensitivity extends into the infra-red to about 1.1 nm.

The lamps also have an infra-red component in their output but it would not be practicable to extend the infra-red emission of the lamps because these are manufactured of glass which have limited transparency beyond a few microns.

It would be expected that by filtering out the shorter wavelengths one would increase the contrast ratio between the lamp and the background. In this case one would also be exploiting the extra sensitivity and atmospheric transparency in the infra-red region. A suitable red filter with IR transparency is all that may be needed. This technique has long been used to improve haze penetration in monochrome photography.

Unlike a normal video application, it will not be necessary to maintain strict linearity of output with light level and it will be adequate to indicate only the presence or absence of light.

The requirement to show only approximate direction indications, say ahead and three sectors either side, above and below, suggests the need for only 49 sensor elements. If this configuration were to be used, each element would cover a much wider acceptance angle than is occupied by the image of a lamp and the background energy would mask the lamp energy.

It will be necessary to estimate the image size of a small lamp viewed from a distance. Simple geometry leads to a figure which is small compared with the pixel cell size. However, for a simple lens the size of the blur patch can be estimated to be about 0.15 mm compared with a typical cell size of 0.0458 mm square. It is therefore to be expected that about 9 cells would be illuminated by a distant point source lamp given only simple optics. Tests using quality lenses have shown that isolated pixels may be

illuminated form a bright point source object.

Each photo-pixel integrates the incident energy and it is important to ensure that not only is the flash energy on each pixel significantly larger than that of the background but that saturation is not reached with the background alone.

For the area arrays, the elements are arranged on a square matrix of various sizes but unlike linear array detectors, the elements are not contiguous but are separated by a gap of similar size to each element. Focussing a point image of a lamp onto the array would imply the possibility of missing some detections and deliberate defocussing may be necessary.

Since the maximum integration time of a focal plane array will be the same as the frame refresh time this should ideally be the same as the expected flash duration to maximise the signal/background ratio.

To observe a xenon lamp a frame rate of 1 Khz would be appropriate but the need to observe filament lamps necessitates that the rate should be about 140 Hz. By choosing the latter rate, there will be an increase in background level and consideration may need to be given to a concept which uses a frame rate of 1 kHz and adopting two parallel processors. One would be dedicated to xenon lights and the other would integrate corresponding pixels from 7 consecutive frames to maximise the signals for rotating reflector filament lights.

This simple approach assumes that the xenon lamps are synchronised with the frame rate and the total energy is implanted onto the sensor within the frame period. In practice they will be asynchronous and measures will need to be adopted to ensure that each flash will be detected with reasonable certainty. This may require the use of more than one sensor array or a significantly different frame period.

The contrast between the lamp and background is determined by the total detectable radiant energy received from each and it may be deduced that using fewer and larger pixels, up to the size of the point image blur patch, does not improve the output contrast ratio since sensitivity will be increased for both lamp and background alike. On the other hand, given a particular cell size it would be beneficial to improve the optical quality of the lens to ensure that maximum lamp energy is implanted on as few cells as possible. The distributed background illumination on the cells is not significantly affected by lens quality.

It will be assumed hereon that an array of 64 × 64 pixels covering a field of 30° will be available.

6. IMAGE PROCESSING.

Visually, a flashing aircraft anti-collision lamp is distinguishable from nearly all other highlight features in the scene because it is

- A near point source;
- Of short duration;

- Periodic.

The processing of the detected signals would therefore be aimed at locating a transient point source highlight appearing in the field of view.

Thresholds will need to be set to ensure that sufficient dynamic range is available and the first of these would be set by an automatic iris adjusted according to the total amount of illumination so as to avoid saturation.

A second threshold would be set by recording the average light level over groups of cells and noting the largest levels in each group. This will be needed to take account of variations of background level within the field of view and due mainly to such factors as bright sky or dark foliage.

Once the detector outputs have been conditioned on a frame by frame basis, the data will be stored in a three dimensional array for processing to establish the factors being sought.

A repetitive flash of 1 Hz will illuminate the array just once among many consecutive frames and the processing must therefore be able to recognise that those particular frames have an illumination which is not present in the preceding and succeeding frames.

The processing required may be considered in stages:

- Preprocessing;
- Enhancement;
- Transformation;
- Filtering;
- Display.

6.1 PREPROCESSING.

This is largely a cosmetic procedure to correct for geometrical distortions but its necessity in this application is adjudged from the following discussion.

To make comparisons between several stored frames of images it is essential to ensure that they are in register so that the comparisons are relevant. Clearly, only image displacements in excess of the inter-pixel angular spacing would be of significance. For a 64×64 array with a 30° field of view this would be about 0.5°.

Consideration will now be given the effects of platform movement assuming a frame rate of 140 Hz.

FORWARD MOTION..... There will be no change at the centre of view of a forward looking camera but at the edges there will be an outward radial movement of the components of the scene.

For an aircraft flying at a height of 250 feet and travelling at 420 knots, the image of the ground at the edge of a 30° field of view, will move by about 5 mins of arc during one frame period of 7 msec and is considerably less than the inter-pixel spacing. This movement will be even less for parts of the scene which are more distant or nearer the cente of the field of view.

If the aircraft were to turn or change attitude, the whole image would move or rotate across the focal plane. The magnitude of these movements may be assessed approximately as follows.

TURNING..... To find the rate at which the image scans across the array due to turning, we can first determine the radius of turn from $R = \frac{V^2}{Tan\beta} \times 14.612 \times 10^{-6}$ where V = True Air Speed (TAS) in knots and β is the bank angle found from $\arccos(1/g)$.

The turn rate follows from the time it takes to fly along the circumference.

A 4g turn at 420 knots gives a turn rate of 10°/sec. The scene then pans diagonally across the camera field of view at 0.07°/frame. A slower aircraft, an A-10 for example, travelling at 150 knots would cause panning at about 0.02°/frame for the same turn rate, again less than the pixel spacing.

ROLLING..... A square array of 64 × 64 pixels has a centre to edge or corner length of 32 pixels and the angular separation between adjacent pixels is therefore 1/32 radian or 1.8°. A roll rate of 120°/sec transfers a point image only 0.84° in the frame time of 7 msec.

Overall it would seem that preprocessing is unnecessary.

6.2. ENHANCEMENT.

This is necessary to ensure that there is sufficient contrast between the lamp signals and the unwanted background signals.

There are two techniques which could be applied. The one exploits optical characteristics of the scene and the other involves manipulation of the data.

The optical technique attempts to emphasise the lamps' spectral qualities relative to the background. Both filament and xenon lamps have wide band emissions extending into the infra-red region, the former having a peak determined by Wien's displacement law and for a filament temperature of 2700° is positioned at about 1μm, well into the infra-red. Xenon lamps have a spikey spectral distribution which is generally elevated in the band 0.8μm-1.1μm.

In practice, both kinds of lamp are enclosed in glass envelopes and this has the effect of attenuating radiation beyond 2μm, as would a glass camera lens. In this application there would seem to be little scope for exploiting the benefits of the longer wavelengths by using more sensitive infra-red detectors unless a glassless emitter based on semiconductors could be found suitable to supplement the existing lamps.

The background is spectrally variable when its components are considered separately.

SKY...... Clear blue sky is evidently rich in the shorter wavelength components as a result of Rayleigh scattering of solar radiation by the air molecules and small particulate matter. Viewed through a deep red filter such a sky appears almost black.

CLOUD...... Mie scattering by larger particles is less selective than Rayleigh scattering and as particle size further increases to include the water droplets and ice fragments within clouds these appear white because the scattering is very uniform across the whole of the visible and infra-red bands.

Haze and mist acquire a hue according to the particle size and varies between blue and white.

WATER...... Surface reflectance from open water decreases linearly from a maximum at $0.5\mu m$ to almost zero at $1.1\mu m$. Reflection from suspended matter within the body of water depends on its composition but all radiation longer than $0.65\mu m$ is absorbed. Consequently, a long wavelength filter would attenuate water reflections.

MINERAL...... This covers soil, rock and buildings constructed of brick or concrete. The reflectance of soil rises linearly over the visual to infra-red range and reaches a maximum reflectance of about 0.5.

VEGETATION...... Apart from the obvious green colour due to absorbtion of the blue and red components by chlorophyll, the reflectance is higher above $0.7\mu m$ due mainly to leaf structure and water content. This varies with type, age and stress state of the plant.

The aircraft carrying the lamps being sought will generally appear as darker shapes against the sky and will obviously remain in close relationship to those lamps. In many cases therefore it would be expected that a lamp will appear adjacent to darker image components.

To achieve ideal contrast enhancement, all backgrounds should be completely suppressed but the considerations given above show that this is not the likely result of any reasonably simple optical filtering technique.

Atmospheric haze also reduces contrast by diluting the scene with scattered shorter wavelength radiation and infra-red filtering would be of benefit to overcome this effect.

Experimentally, the use of a near infra-red filter has been found to reduce most of the illumination from blue sky but although cloud and vegetation have high infra-red reflectance there is generally a useful reduction.

Enhancement is also to be attained by manipulation of the data. Generally, a scene will have a range of brightness levels which subsequent encoding will record as an 8 bit word for each pixel. Although 256 brightness levels would then be available, the typical scene would only cover a limited range and it is possible to produce a histogram of the distribution of pixel illumination levels. This could be for the whole

array or any sub set of the array. Apart from occasional occurences of very bright or very dark parts of the scene the distribution would not cover the full dynamic range of the sensor and only a limited range of values would be recorded. Contrast could therefore be improved by artificially stretching the distribution.

In this application, only the highlights due to flashing lamps are of interest and consequently it should only be necessary to extract the highlight data and suppress the remainder. In essence this involves non-linear stretching to the full dynamic range and applying a lower threshold.

Of the various stretching rules which have been adopted for applications where interest lies with the whole of the available data, few would be relevant to this problem. In principal, the technique is to distort the recorded histogram so as to fit some other distribution, e.g. Gaussian but the results vary with the input data.

There will be occasions when the sun will be in direct view and dominate the overall brightness by local saturation. If it be assumed that the proposed device covers a field of 30°, the sun's visual diameter of 0.5° would cover an image area of about 1 pixel. Since the peak recordable brightness level possible would be 255, the mean level contributed by the sun would therefore be $255/64^2 \approx 1/16 \cong 16$ levels. Flare and halation, would however worsen the effect than this simple calculation suggests.

On the assumption that no anti-collision light is expected to be as bright as a clear sun, a second upper threshold will ensure that excessive outputs are eliminated. In the event of a dimmed sun being visible because of cloud or haze, there would probably be few problems but the fact that the sun is a continuous source would be a feature which would aid with its elimination.

For the purposes of extracting highlight information only, it is appropriate to set the brightest to the value 255 and then adaptively stretching the remainder of the scene downwards. A threshold could then be applied to create binary values of pixel data with all the lower values set to "0" and the upper ones to "1". The entire enhancement process could be implemented by means of a ROM look-up table.

Consideration should be given to fact that the average scene brightness will also vary and some measure of level control is desirable and could be based on an iris driven by the mean output of the detector array In practice the lower part covering the land will also be different from the upper dominantly sky area and this can be accounted for in the processing.

6.3 TRANSFORMATION.

The purpose of this stage is to reveal those areas where features characteristic of flashing lights may be recognised and the process in its simplest form involves the production of composite images from two or more recorded images.

Conceivably, these could be from a *multispectral* set of images made in different spectral bands to exploit identifiable characteristics of the lamps being sought. However, because of the different natures of xenon and filament lamps, the composite image would best be from a *multitemporal* image set recorded at different times.

Transformation may involve trivial arithmetic operations such as subtraction or more complex operations such as Fourier transformation. Furthermore, it may be expedient to adopt transformation to recognise one characteristic and then use filtering to eliminate the others. The use of a multitemporal image set implies that any transformation process would reveal time dependent characteristics, in this case the duration and possibly periodicity, rather than image size.

A Fourier processor would classify all periodic components and subsequent filtering would isolate those conforming to the range expected of anti-collision lights, namely between 0.5 Hz and 2 Hz. There would be occasions when several lights are present in the same image set and interpretation may then become difficult.

To recognise a 2 sec flash period would require the storage and processing of over 1 Megabyte of image data and considerably more to establish a persistent periodicity. The search for periodicity is evidently costly and although within the capabilities of a parallel processor, it is also evident that valuable human decision and action time would be lost whilst the equipment is establishing the lamp's credentials. It is therefore considered that processing to reveal periodicity is unnecessary and possibly hazardous.

In the wider context, the process is one of image recognition where it is desired to reveal the presence of some expected shape such as the outline of a aircraft. In these cases the problem is influenced by orientation and aspect and circular invariant transforms have been devised to recognise object shapes in spite of these variations. In the case of the target image being a flashing light, the problem is simplified because it is essentially a single point with circular symmetry.

The transformation processor exploits the fact that the background scene changes but little between frames. By subtracting corresponding pixel values from consecutive frames, the occurence of a transient highlight should be recognisable. As proposed, the pixel values will be either '0' or '1' and subtraction in this context could be replaced by an 'EXCLUSIVE OR' process. Although both processes result in composite images from both preceding and succeeding frames, one of these will be inverted for the subtraction method.

In the event of a single flash being so timed as to illuminate consecutive frames or the chosen frame period is significantly shorter than the flash duration, the processing will need to take account of this possibility.

It will be appreciated that these processes are self filtering since they do more than just recognise the presence of transient highlights, they also eliminate those which have a duration longer than one frame period.

Since the displayed resolution need only be relatively coarse with, say, an indication of "AHEAD" and three other sectors either side and similarly for elevation, adjacent lines or columns of the detector array could be grouped to provide a single output for further processing. Thus, if a transient illumination of one pixel occurs, then a set of eight adjacent lines and columns of a 64 × 64 array are set to "1" and the two outputs used to drive the display. One benefit of such data compression results when two or more synchronous flashing lamps are fitted to an aircraft and duplicated processing is avoided but the wisdom of this technique would need to be proved.

6.4 FILTERING.

Filtering in this context implies signal manipulation and not optical filtering and is required in order to separate highlights whose characteristics conform to those expected of anti-collision lights. It is therefore feasible to include this process before or after transformation but it will be self evident that the methods to be described below may not be appropriate for image data which has been compressed.

Filters would be used to

1) remove those highlight signals which are grouped over a larger number of pixels than would be expected from a single lamp;

2) eliminate those whose flash duration is longer than expected.

As has been seen, some filtering can be done in combination with the transformation stage to isolate short flashes and further filtering may only be needed to isolate those having small image dimensions. This involves inspecting individual frames and a simple technique is based on a moving average filter. This would best be implemented with a two-dimensional moving window having an area of 3×3 pixels and the objective would be to average the values over the area and subtract the central pixel value. If all nine pixels were of equal value then the output would be zero but if the centre element alone was high the output would be a maximum. Only images smaller than nine pixels would therefore be output. This process is equivalent to implementing a high-pass filter by removing the low frequency components from the original.

In many image processing applications, median instead of mean values are used to produce a smoothed background. The pixel amplitudes within the window are placed in rank order and the middle value selected. This has the advantage of being less influenced by extremes and produces integer values which already exist. With simple logic values of "0" or "1" for each pixel, this would not be a meaningful process but it could be applied before thresholding. The benefits to be gained must therefore be assessed against the increased computation required.

Other filtering processes which are more akin to differentiation are also possible. Such methods could be of value if the image itself were diffused due to non-optimum optics and atmospheric effects producing a spreading function of the point image. The method requires the passing of a weight matrix over the array. The weights used are subject to choices but the "Image minus Laplacian" operation may be appropriate. The Laplacian operator in effect produces a second difference function which emphasises changes between pixels and by subtracting this from the original image has the effect of de-blurring. Although a two part process, the complete operation can be carried out with a single pass of the matrix

$$\begin{matrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{matrix}$$

Although logical input values have been assumed, it is evident that this and similar

processes results in outputs of varying magnitudes and a further threshold needs to be applied.

7. DISPLAYS.

The choice of display is subject to limitations set by the cockpit environment but it is probably too early to give an in depth consideration to display requirements.

It was suggested earlier that the only indications required may be that of sectors corresponding to "AHEAD" and three other sectors either side. The need for elevation information is not certain at this stage but may be of similar resolution.

Conceptually, the indicator could be within a Head Up Display (HUD) to show the approximate direction of a transient point source highlight but some other form of daylight viewing display would be necessary for demonstration purposes. This could be a liquid crystal display of a few segments corresonding to coarse bearing and elevation indications.

In association with the display, there would also be a need for some form of alarm but detail consideration of this should be deferred.

8. EXTENSION OF CONCEPT.

A possible extension to the system would allow the detection of the silhouette of an aircraft against a light sky background. This would supplement the detection criteria for those aircraft not carrying anti-collision lights. The processing would be more difficult because the image would be larger than the point sources previously considered and flexible pattern recognition would be needed to identify, unambiguously, aircraft of any size and aspect.

9. HORIZONTAL POSITION INDICATION.

Aviators have often expressed a need for a means of visually assessing the relative height of another aircraft, particularly when it is the same as the observer.

Schemes have been suggested which involve modifying the aircraft lamps in such a way as to uniquely code the observed light when viewed within the same horizontal plane but the concept being proposed here would allow the horizon plane to be recognised without the need to install special lamps and would be performed in the observing aircraft.

Assuming that a gyro platform is available, the pitch and roll angle could be used as a horizon indicator in the form of a template against which the image is compared. If an anti-collision light is detected and found to be in the plane of the horizon, a special flag could be set to warn the pilot that that aircraft is at the same height.

10. CONCLUSIONS.

It would seem that, provided difficulties in establishing the presence of a small

transient light source against relatively bright backgrounds can be resolved, the concept for an anti-collision light detector based on modern image processing techniques is feasible.

Although this note has concentrated on the type of processing which could be adopted as opposed to what is practical and should be adopted, most of what is desirable could be implemented with a transputer processor within the camera head.

At the expense of processing time and real money, there is a balance to be struck between having an all embracing device which gives clear and unambiguous indications to the pilot and the simpler detector which allows pilots to make their own decisions as to what is or what is not a hazard. It would seem that the balance would be to provide clear indications of potential hazards by emphasising light images which could have been visually missed and which pass certain basic recognition criteria and leave the pilot to make the final appraisal.

It is therefore proposed that effort should be directed to the design and manufacture of a prototype anti-collsion light warning aid along the lines described.

FURTHER READING.

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Abstract

Recent instances of mid-air collisions and near-misses between aircraft at low level have emphasised the need for some form of aid to provide earlier visual warning of potentially dangerous situations. This memorandum describes the nature of the problem to be overcome and proposes the use of a cockpit image sensor and advanced image processing techniques.

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